

## **Sonobuoy-Based, 3-D Acoustic Characterization of Shallow-Water Environments**

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### **LONG-TERM GOALS**

The long-term goal of this research is to increase our understanding of shallow water acoustic propagation and its relationship to the three-dimensionally varying seabed and water column environments.

### **OBJECTIVES**

The scientific objectives of this research are: (1) to develop high-resolution methods for characterizing the spatial and temporal behavior of the normal mode field in shallow water; (2) to use this characterization as input data to inversion techniques for inferring the acoustic properties of the shallow-water waveguide (both the seabed and the water column); and (3) to use this characterization to improve our ability to localize and track sources.

### **APPROACH**

An experimental technique has been developed for mapping the wavenumber spectrum of the normal mode field as a function of position in a complex, shallow-water environment [1]. By describing the spatially varying spectral content of the modal field, the method provides a direct measure of the propagation characteristics of the waveguide. The resulting modal maps can also be used as input data to inverse techniques for obtaining the laterally varying, acoustic properties of the waveguide, specifically the sound speed profile  $c(r,z)$  as a function of range  $r$  and depth  $z$  in the seabed [2-7]. The experimental configuration consists of a moored, drifting, or towed source radiating one or more pure tones to a field of several freely drifting buoys, each containing a hydrophone, GPS navigation, and radio telemetry, as shown in Fig. 1. A key component of this method is the establishment of a local differential GPS system between the ship and each buoy, thereby enabling the determination of the positions of the buoys relative to the ship with submeter accuracy [8,9]. In this manner, the drifting buoys create synthetic aperture horizontal arrays along which the modal evolution of the waveguide can be observed in the spatial domain, or after Hankel transforming the pressure field  $p(r)$ , in the horizontal wavenumber domain  $k_r$ , where the range-dependent seabed properties manifest themselves through the measured range-dependent eigenvalues  $k_n(r)$ . A broadband variant of this method, in

which impulsive signals are transmitted between a fixed source and receiver, has also been developed and applied successfully to the geoacoustic and water column inverse problems [10,11]. Finally, these high-resolution measurements provide new insights into source localization and tracking techniques [12-17].

## WORK COMPLETED

To date, five successful Modal Mapping Experiments have demonstrated the effectiveness of the modal mapping technique in acoustically characterizing shallow-water waveguide environments and in tracking low-frequency sources. Furthermore, MOMAX V, conducted on 5-18 March 2011 aboard the R/V Sharp, demonstrated that the method could be successfully executed using COTS, GPS-capable AN/SSQ-53F sonobuoys, instead of the MOMAX research buoys. Specifically, narrowband and broadband signals were transmitted in the band 50-1000 Hz using a drifting and towed NUWC J15 source at 56 m depth and a drifting and towed NUWC G34 source at 8 m depth. Data were received on 4 drifting MOMAX buoys, each having hydrophones at 61 m and 64 m depths as well as several 53F sonobuoys with a hydrophone at 61 m depth. In order to assess the practicality of using sonobuoy data for geoacoustic inversion applications, the two types of buoys were deployed in a co-located configuration on several occasions by connecting the upper portions of the buoys with a 4.6 m cable. This arrangement ensured that the two types of buoys were acquiring data under the same environmental (specifically, seabed) conditions. The bathymetry for the experimental area, as well as the ship and buoy tracks for the co-located buoy deployments are shown in Fig. 2.

## RESULTS

The spatially varying pressure field measurements are then input to a perturbative inversion scheme which can be implemented using the formalism of linear inverse theory. The results of this inversion process for the Shemp/SB810 co-located buoys are shown in Fig. 3 [G.V. Frisk *et al*, “Modal mapping experiment and geoacoustic inversion using sonobuoys,” *IEEE J. Ocean. Eng.*, vol. 40, no. 3, pp. 607-620, Jul. 2015 (DOI: [10.1109/JOE.2014.2362838](https://doi.org/10.1109/JOE.2014.2362838), (*IEEE Xplore Early Access*, 4 Dec 2014))]. For each type of buoy, the eigenvalues at 50, 75, 125, and 175 Hz were used as input data to a multi-frequency, perturbative inversion algorithm to obtain the bottom models shown in Fig. 3. The two seabed profiles are in excellent agreement with one another and are consistent with the results of previous experiments conducted in the same general area. Note that, based on other measurements, the density was assumed to be 1.6 g/cc, and attenuation and shear effects were not included in these inversions. This approach also generates resolution and variance estimates for the estimated geoacoustic parameters. These results for the SB/810 combination are shown in Table I, which provides an encouraging, quantitative evaluation of the accuracy associated with the inferred geoacoustic models in Fig. 3.

The most recent Modal Mapping Experiment (MOMAX V) demonstrated that the method could be successfully executed using COTS, GPS-capable 53F sonobuoys, instead of the MOMAX research buoys. This result has provided the incentive to initiate the development of a technique in which multiple (25-30) sonobuoys are used to create 2-D synthetic aperture, planar arrays which measure the pressure field  $p(x,y)$ . This dense field of receivers, when combined with an appropriate spatial interpolation technique, will provide the opportunity to compute a 2-D Fourier transform to estimate the wavenumber spectrum as a function of the lateral wavenumbers  $k_x$  and  $k_y$ . The eigenvalue behavior  $k_n(x,y)$  can then be used to invert for the 3-D acoustic properties of the waveguide,

specifically  $c(x,y,z)$  in the seabed. The 3-D perturbative inversion method under development combines a Green's function approach with the Born approximation.

## **IMPACT/APPLICATIONS**

This work shows that an experimental configuration consisting of a drifting or towed source and freely drifting receivers, all with precision GPS navigation, can provide an effective way to characterize the modal characteristics and acoustic properties of a shallow-water waveguide (both the seabed and the water column). Furthermore, the results show that this technique can be implemented using COTS sonobuoy receivers and potentially can be applied during routine operations conducted by NAVAIR. In addition, the creation of synthetic aperture, horizontal receiving arrays, which constitute the cornerstone of this method, may offer an effective new technique for localizing and tracking sources of unknown, quasi-stable frequency in shallow water.

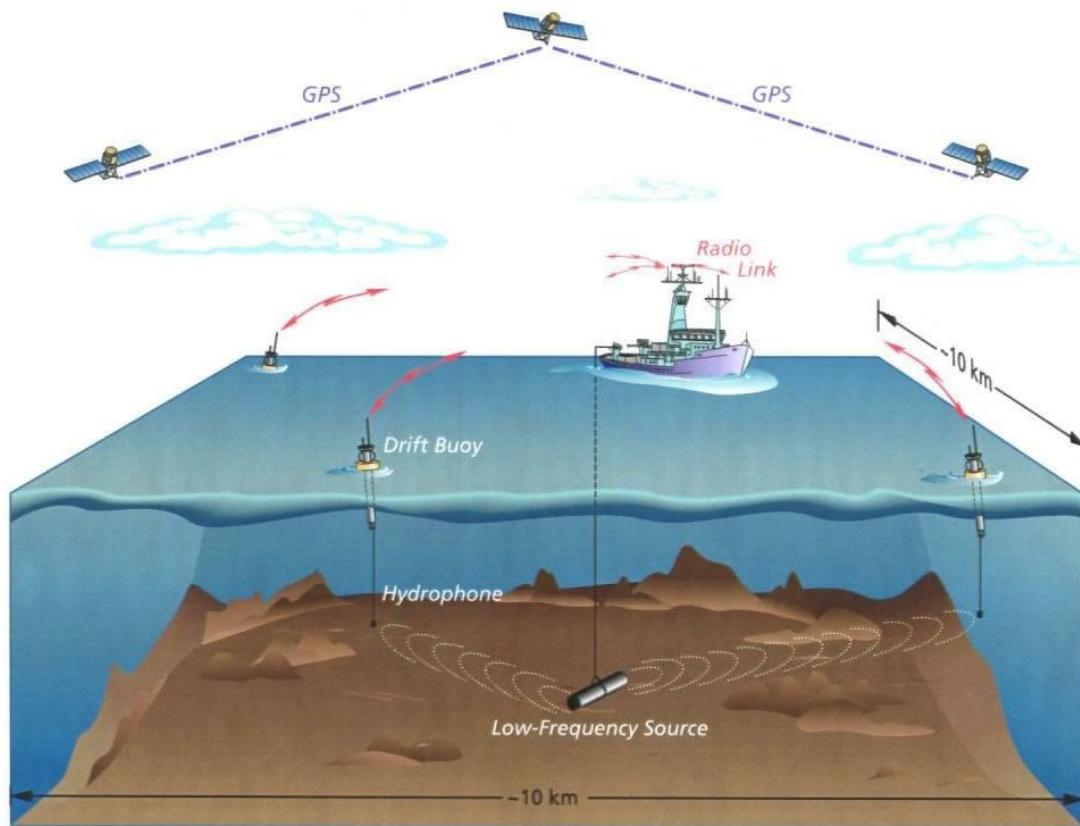
## **TRANSITIONS**

This work represents a major step toward transitioning the experimental method to NAVAIR (POC: David Seevers) and the modal inversion technique to NAVOCEANO (POC: David Harvey), thereby providing the capability for NAVOCEANO to upgrade/populate shallow-water LFBL databases in existing/new operational areas. The implementation of the MOMAX methodology and geoacoustic inversion technique in a NAVAIR operational scenario could occur in conjunction with the following schedule [18]:

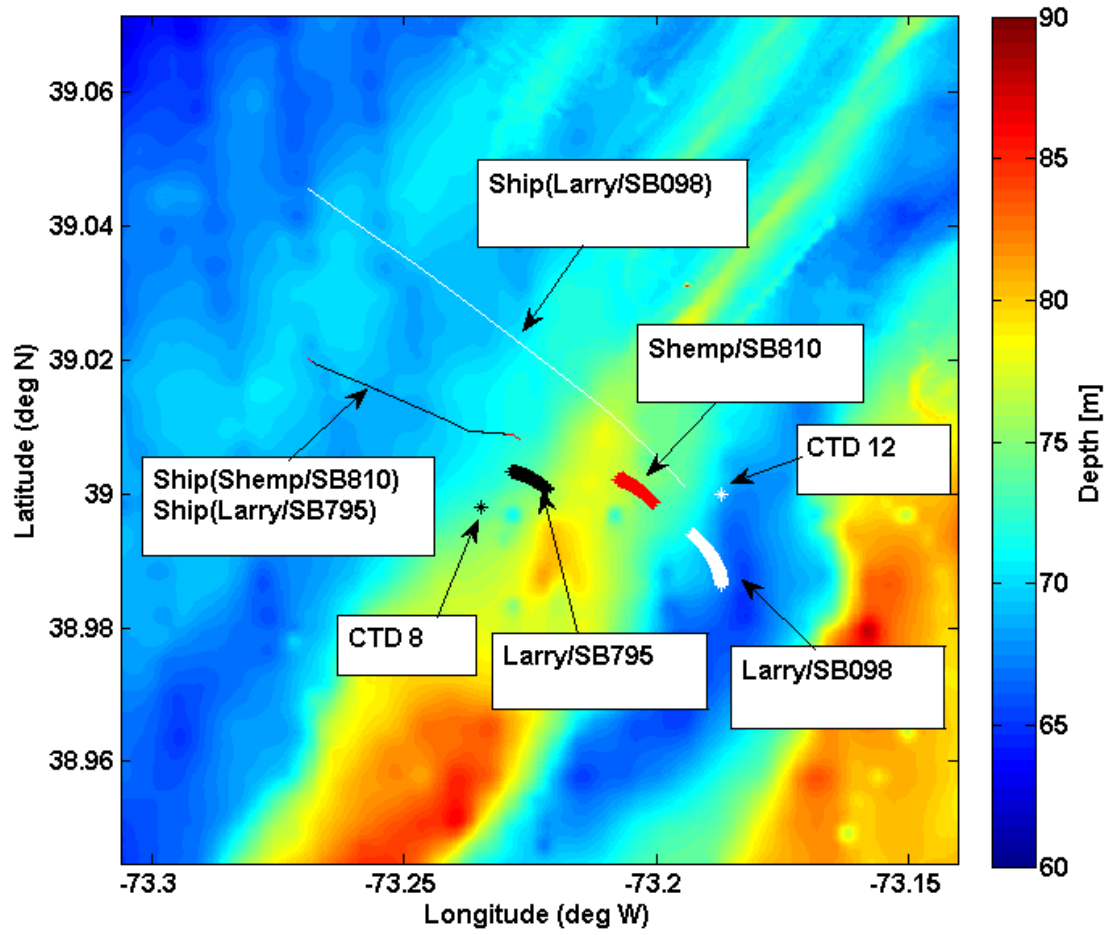
The Navy plans to incorporate GPS into the ADAR sonobuoy receiver in the fourth quarter of FY14, with Fleet availability in the third quarter of FY16, and to incorporate GPS into the coherent 950 Hz, MAC (SSQ-125) sonobuoy source in the fourth quarter of FY14, with Fleet availability after FY16.

## **RELATED PROJECTS**

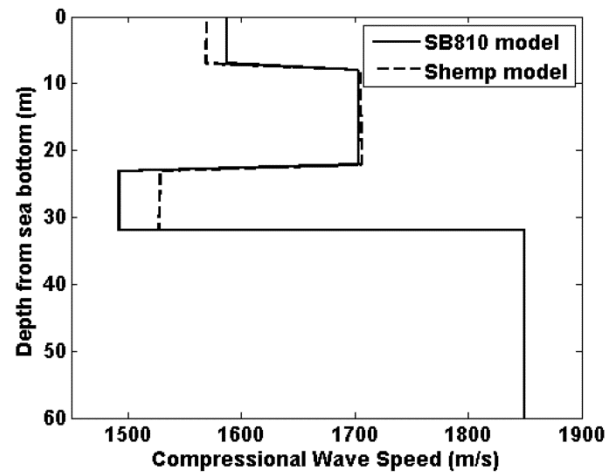
These efforts are being closely coordinated with the planning and design of the ONR 2017 Seabed Characterization Experiment in the New England mud patch, which has extensive spatial geoacoustic variability [19]. Specifically, the design of a future experiment, which uses a large number of sonobuoys (e.g., 25-30) to collect data on a 2-D synthetic aperture, planar array, has been initiated. The proposed experiment will incorporate recent developments in the use of Software Defined Radio (SDR) to receive and process radio signals from a large number of sonobuoys [20]. This approach utilizes laptop computers, rather than standard sonobuoy receivers, for its processing platforms and will enable the determination of the 3-D geoacoustic properties of the waveguide in an efficient and cost-effective way.



**Figure 1: MOMAX experimental configuration.**



*Figure 2: Bathymetry of the experimental area showing ship and buoy tracks for the co-located buoy deployments in MOMAX V.*



*Figure 3: Bottom models estimated from data collected by Shemp and SB810.*

**TABLE I**  
**AVERAGE VALUES OF DEVIATION AND RESOLUTION LENGTHS FOR MODELS FROM**  
**SHEMP AND SB810 DATA**

Layer Number	Shemp		SB810	
	Deviation (m/s)	Resolution (m)	Deviation (m/s)	Resolution (m)
Layer 1	1.33	5.59	1.67	6.4
Layer 2	2.12	9.48	3.19	10.9
Layer 3	3.01	7.22	4.27	7.21

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## PUBLICATIONS

- P. Tyack, G. Frisk, E. Urban, and S. Seeyave, "International Quiet Ocean Experiment Science Plan," 103 pages (2015).
- G.V. Frisk, K.M. Becker, S.D. Rajan, C.J. Sellers, K. von der Heydt, C.M. Smith, and M.S. Ballard, "Modal mapping experiment and geoacoustic inversion using sonobuoys," *IEEE J. Ocean. Eng.*, vol. 40, no. 3, pp. 607-620, Jul. 2015 (DOI: [10.1109/JOE.2014.2362838](https://doi.org/10.1109/JOE.2014.2362838), (*IEEE Xplore Early Access*, 4 Dec 2014).

## **HONORS/AWARDS/PRIZES**

G.V. Frisk, Pioneers of Underwater Acoustics Medal of the Acoustical Society of America, 2010.

G.V. Frisk, President, Acoustical Society of America, 2010-2011.

G.V. Frisk, Co-Chair, Research Initiative for an International Quiet Ocean Experiment.

G.V. Frisk, Chair, International Organization for Standardization/Technical Committee 43/  
Subcommittee 3 (ISO/TC 43/SC 3) on Underwater Acoustics.